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Plant Species Dynamics and Recovery from Sites Routinely Maintained by Application of Herbicides in the Ile-Ife Municipality, Osun State, Nigeria

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Abstract

This study investigated the effect of indiscriminate application of herbicides on weed recovery in urban environment in Ile-Ife, Osun State, Nigeria. A survey was carried out to identify sites maintained by the application of herbicides (test plots) and those without herbicide history (control plots). Comprehensive enumeration and identification of plant population to species level were carried out during recovery on four different experimental plots. Sorenson's index of similarity was used to determine the relationship in plant species composition between plots treated with herbicides and the untreated plots and the relationship in plant species composition between plots treated with herbicides and the soil seed bank. A reduction in weed species density was achieved after each successive herbicide application. Although the vegetation was not allowed to restore to an earlier state due to the incessant application of herbicides, the trend of increasing plant species was observed in all the treated plots with a change in weed species composition. A low similarity index was observed between the composition of the vegetation in the treated plots and the control vegetation at all visits. A low similarity was also observed between the aboveground vegetation and the seed bank in all the plots. The result of this study has shown that the population dynamics of weeds in the herbicide-treated plots have practical implications in the use of herbicides for general weed control because it provides an opportunity to monitor the response of weeds to extreme dosages, extreme combinations of herbicides and persistent applications.

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Introduction

The use of herbicides for vegetation maintenance in urban settings is a development that exposes not only the soil surface but other organisms (microorganisms, animals and humans) to different levels of health hazards [1]. In most cases, the application of herbicides is done by amateurs/unskilled professionals who are not aware of the adverse effect of chemicals on their health. On the other hand, the use of non-chemical (cultural, mechanical and biological) weed control is becoming increasingly important and popular in developed countries in response to the goal of protecting the human population and the health of the ecosystem. Although regarded as a cost-effective and fast method of weed eradication in the urban setting in developing countries, especially in Nigeria, the use of chemicals for weed control has generated concerns about their non-target effects on various aspects of the ecosystem and the future recovery of such ecosystems. For example, herbicide residues have been implicated as possible carcinogens, with symptoms such as fatigue, vomiting, irritation of the eyes and skin-associated problems [2].

Despite the hazards associated with herbicide use, indiscriminate use persists with concentrations arguably greater than reported in agricultural soils, thus represents a higher risk factor in urban areas [3, 4]. Several studies have been carried out to study plant dynamics during succession in arable lands [5-7] with the seed bank opinionated to play a major role in natural regeneration and restoration after disturbances [8, 9]. Therefore, the capability of plant species to produce seeds that remain viable in the soil allows them to bridge temporally unfavorable habitat conditions for germination and establishment and ensure species survival. The seed bank in the urban environment is characterized mainly by short-lived plant species that are depleted every year during the growing season and reloaded with new seeds during the next seed set and dispersal period [10]. Consequently, practices that intermittently interrupt plant species growth and seed set will cause a decline in seed composition and richness of the soil seed bank.

Comparative studies between the aboveground vegetation and the soil seed bank in many instances have shown a low similarity [11-13]. This is a suggestion that the restoration of the aboveground vegetation after disturbance may require the introduction of targeted plant species. Limited potential for restoring woody vegetation solely from soil seed banks was reported by Savadogo et al. [14], where woody species, relied more on recently-shed seeds trapped in the standing dead biomass and litter on the ground than soil seed banks for regeneration. The aim of this study was, therefore, to investigate the influence of soil seed bank on the recovery of an urban ecosystem where the indiscriminate use of herbicides is routinely done to control the vegetation and to understand plant species dynamics in such ecological settings.

Materials and Methods

Experimental plot description

The study was carried out in a newly opened section of an urban environment in Ile-Ife (Latitudes 7°28′N and 7°45′N and longitudes 4°30′E and 4°34′E), Osun State, Nigeria. Before the establishment of the experiment, a reconnaissance survey of the study area was done to identify places where different herbicide brands (*e.g.*, weed crusher, force off, weed off, sarosate, aminoforce, force diuron) containing different active ingredients (paraquat, glyphosate, diuron, etc.) were indiscriminately used to maintain the vegetation. Four experimental plots designated as A, B, C, and D were selected (Fig. I). A site often 10 m apart from the identified locations with no history of herbicide use served as the control. The plot A (15m × 15m) is located beside a residential home in Olasode. Plot B is located on Eleweran, Ede Road, Ile-Ife and consists of an uncompleted building whose front yard was maintained by different types of herbicides. Plot C is a religious ground premise in the Ife City while plot D is a residential house with an uncompleted building in the compound located in the Parakin. A suitable control was not found for plot D, and due to the introduction of other management practices, the site was excluded from the plant species enumeration.

Plant identification of the experimental plot and soil seed bank

Identification of plants on the aboveground vegetation of the selected plots was carried out using the methods of Weeds of West Africa [15] and Flora of West Tropical Africa [16]. The plant species with doubtful identities were collected and taken to the IFE Herbarium for proper identification. Continuous visits were made to the selected plots once every month for two years before the experiment was terminated. Three plots (5m × 5m) were marked in each of the identified four locations along with control plots for soil sampling. The soil samples

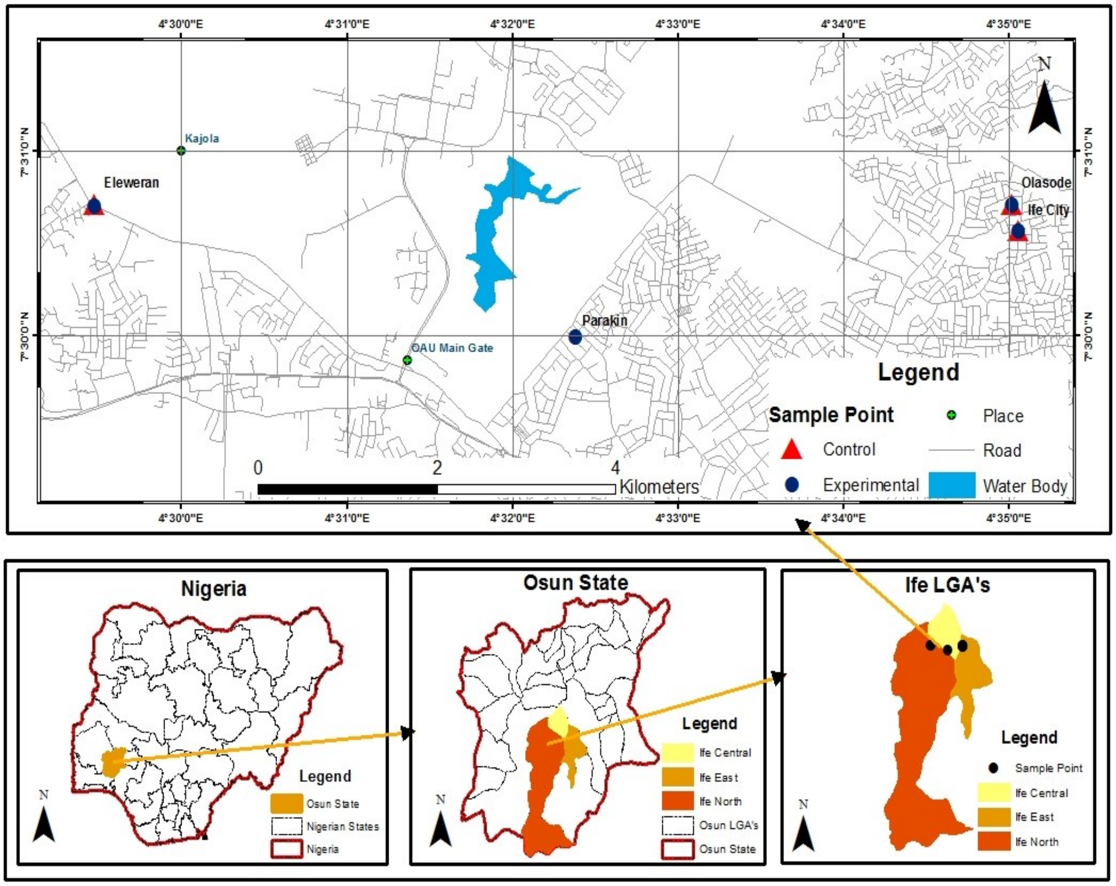

Fig. I Map showing locations of urban environment study sites in Ile-Ife, Osun State, Nigeria.

collected were air-dried and plant fragments and stones were removed. The direct germination method of Thompson and Grime [17] was used to assess the species composition of the soil seed bank. Briefly, air-dried soil samples weighing approximately 450 g were evenly spread to a depth of 2 cm inside germination plates of 16 cm width. The plates were perforated at the bottom and watered regularly. Emerging seedlings were identified, counted and uprooted or replanted for later identification. Seedling emergence tests in the plates were terminated when seedlings stopped emerging for a range of three consecutive weeks and after sifting and carefully certifying that no seeds remained in the plates. The species composition and relative abundance of species were determined for plant communities in the treated plots, control plots and the seed bank. The similarity between the experimental plot and seed bank was evaluated following the method of Sorenson [18], based on the existing species richness of all the sites as follows:

$$\text{SSI} = \frac{2C}{A+B} \times 100$$

where SSI is Sorensen's similarity index, C is the number of species common in A and B, while A and B sites are the total numbers of species present in site A and site B, respectively.

Results

Plot A experimental site

The vegetation at plot A experimental site was recovering from a recent application of herbicide at the time of first visit. The distribution of plant species identified at the experimental plot into their different families and habits are shown in Fig. 2. The dominant plant species in the recovering vegetation community were *Centrosema pubescens, Bidens pilosa* and *Talinum triangulare.* Following another episode of herbicide application and a time frame given for the plot to recover, *Mimosa pudica* and *Merremia aegyptia* occurred in abundance. Following the setting of the harmattan season, *Centrosema pubescens* and *Merremia aegyptia* occurred both in large populations and as dominant species. *Mimosa pudica*, *Talinum triangulare (*stressed*), Tridax*

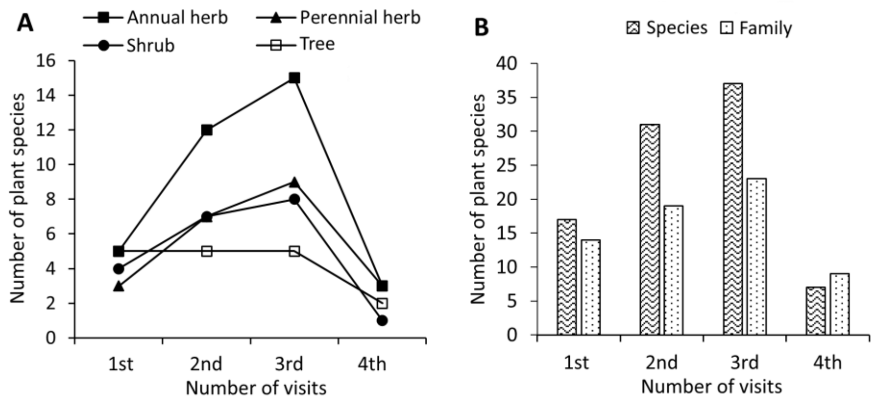

Fig 2 Recruited numbers of weed species at plot A experimental site. (**A**) Distribution of plant species into different habits and (**B**) distribution of plant species into different families.

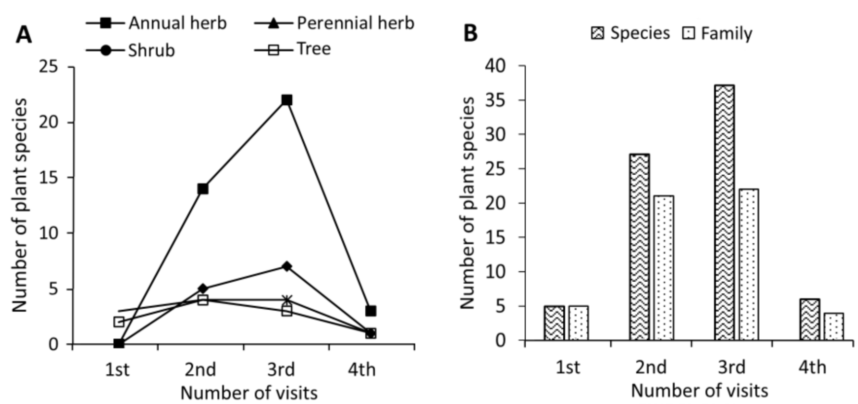

Fig 3 Weed species at plot B experimental site. (**A**) Distribution of plant species into different habits and (**B**) distribution of plant species into different families.

procumbens and *Dalbergiella welwichii* occurred in a few populations. A few stands of *Bidens pilosa,* young saplings of *Carica papaya* and *Guajava psidium* were also observed. Some plant species resident on the plot in spite of the treatment applied include *Mallotus oppositifolia, Newbouldia laevis* and *Dalbergiella welwichii.* The plant species enumerated on the control plot are listed in Table 2. Plant species found common to both the control and experimental plots include *Mallotus oppositifolia, Newbouldia laevis,* and *Dalbergiella welwichii*. The Sorenson similarity indices between the control and experimental plots at different periods of visitations are presented in Table 1.

Table 1 Similarity indices between the experimental and control plots at different visitations.

Control	Plot location			
	A	B	C	D
A	0.4103	0.4528	0.4407	0.3226
B	0.2105	0.2927	0.3137	0.2000
C	0.3158	0.5000	ND	ND

ND = not determined

Plot B experimental site

The plot B experimental site had recently been sprayed and the vegetation cover appeared burnt with a standing crop of dead plants at the first visit. The dominant but stressed plant species observed was S*tachytarpheta cayennensis* with leaves appearing cupped or crinkled (Fig. 4A). The dynamics of plant species in their different families and habits identified at the experimental plot at different visits are shown in Fig. 3. At recovery on a second visit in 2014, *Bidens pilosa* was present in a contagious population. Further visitation showed that the vegetation community was still recovering with new plant species recruited. *Cleome viscosa, Laportea aestuans, Ageratum conyzoides* and *Hyptis suaveolens* seedlings were among the recruited plants present in abundance. *Trema guineensis,* a perennial shrub and a typical forest regrowth species was also

Fig. 4 Experimental plots sites. (A) Experimental plot B recently treated with herbicides and the presence of standing dead vegetation; (B) experimental plot B in its recovery state consists of a variety of weedy plant species, mostly from the *Asteraceae* family; (C) the premise of the religious house at plot C used as experimental plot and (D) *Ageratum conyzoides* at the site located in plot D.

observed. *S. cayennesis* stands were, however, dying in the vegetation. At the final visit to the plot in 2015, the flora in its recovery state was occupied by a variety of weedy plant species mostly from the *Asteraceae* family (Fig. 4B). The dominant and most abundant weed species were *Bidens pilosa*, *Gomphrena celosioides, Hyptis suaveolens* and *Chromolaena odorata*, which were also observed on the control plot (Table 2). *G. celosioides* occupied only a portion of the experimental plot in a large population. While *H. suaveolens* seedlings were few, *C. odorata* seedlings were young and scantily represented. *Stachytarpheta cayennesis* once present in the plot had, however, been lost.

Plot C experimental site

Standing dead crop in the vegetation indicating a recently sprayed site was encountered at the first visit to Plot C (Fig. 4C). Also present in the background is a well that served some of the members of the community. The dynamics of a number of plant species, families and habits identified at the experimental plot at different visits are shown in Fig. 5. At recovery, the vegetation on the plot consisted more of *Eleusine indica* with dotted forbs. Other plant species present, include *Sida acuta, Chromolaena odorata* and *Mimosa pudica*. The plant species present at the control site include *C. odorata, F. exasperata*, *Malotus oppositifolius*, while *Eleusine indica* and *Calopogonium mucunoides* occurred more at the road side. A small number of *S. acuta* was also

Table 2 Composition of plant species at the control plots A, B and C.

Name of species	Family	Habit	A	B	C
Aspilia africana (Pers.) C. D. Adams	Asteraceae	Perennial herb	+	+	-
Axonopus compressus (Sw.) P. Beauv.	Gramineae	Perennial grass	+	-	-
Bidens pilosa L.	Asteraceae	Annual herb	+	+	-
Calopogonium mucunoides Desv.	Fabaceae	Perennial herb	+	+	+
Centrosema pubescens Benth.	Fabaceae	Perennial herb	+	-	-
Citrus sinensis (L.) Osbeck	Rutaceae	Tree	+	-	-
Chromolaena odorata (L.) R. M. King & H. Rob.	Asteraceae	Shrub	+	+	+
Commenlina benghalensis L.	Commelinaceae	Annual herb	+	-	-
Dalbergiella welwitschii (Bak.) Bak. f.	Fabaceae	Shrub	+	+	-
Desmodium scorpiurus (Sw.) Desv.	Fabaceae	Perennial herb	-	-	+
Desmodium triflorum (L.) DC	Fabaceae	Annual herb	-	-	+
Eleusine indica (L.) Gaertn	Gramineae	Annual grass	+	-	+
Euphorbia graminea Jacq.	Euphorbiaceae	Annual herb	+	-	-
Ficus exasperata Vahl	Moraceae	Tree	+	-	+
Gomphrena celosioides Mart.	Amaranthaceae	Perennial herb	+	-	-
*Lonchocarpus sericeus (*Poir.) HB & K.	Fabaceae	Tree	+	-	-
Laportea aestuans (L.) Chew	Urticaceae	Annual herb	-	+	-
Mallotus oppositifolius (Geiseler) Müll. Arg.	Euphorbiaceae	Shrub	+	+	+
Mimosa pudica L.	Fabaceae	Perennial herb	+	+	-
Momordica charantia L.	Cucurbitaceae	Perennial herb	-	+	-
Morinda lucida Benth.	Rubiaceae	Tree	+	-	-
Newbouldia laevis Seem	Bignoniaceae	Tree	+	-	-
Paspalum species.	Poaceae	Perennial grass	+	+	-
Pouzolzia guineensis Benth.	Urticaceae	Annual herb	-	+	-
Senna hirsuta (L.) H. S. Irwin & Barneby	Fabaceae	Shrub	+	-	-
Sida acuta Burm.f.	Malvaceae	Perennial herb	+	+	+
Sporobulus pyramidalis P.Beauv.	Gramineae	Perennial grass	+	-	-
Spilanthes filicaulis (Schum. & Thonn.) C. D. Adams	Asteraceae	Annual herb	-	+	-
Stachytarpheta cayennensis (Rich.) Vahl	Verbenaceae	Perennial shrub	-	+	-
Synedrella nodiflora (L.) Gaertn.	Asteraceae	Annual herb	-	+	-

\+ Present; - Absent

present in the control population (Table 2).

Plot D experimental site

At the Parakin plot, plant species dominating the plot include *Tridax procumbens, Oldenlandia corymbosa* and *Eleusine indica.* A follow-up visitation of the plot after a year of monitoring reveals that *Ageratum conyzoides* existed singly in numerous populations. The application of herbicide was, however, discontinued when the introduction of rabbits as free-range animals on the plot was negatively affected (Fig. 4D). All vegetation was thus removed manually and the soil was left bare.

Soil seed bank recruitment

The result of the soil seed bank from the different plots is shown in Table 3. In plot A, six plant species contributed 65 individuals to the seed bank. *Talinum triangulare* had the highest relative abundance of 63.08% followed by 24.62% of *Peperomia pellucida*, and an unidentified member of the family of *Poaceae* (7.69%). Out of these six plant species, only three were present in the aboveground vegetation. A low Sorensen's similarity index (SSI) as shown in Table 4 was obtained for the seed bank plant community and the aboveground vegetation in the experimental plot at the different period of plant species enumeration. A total of 42 individual plant species were enumerated from the seed bank of the plot B experimental site comprising seven plant species belonging to seven different families. *Talinum triangulare* had a higher abundance of 52.38% followed by *Ageratum conyzoides* with 14.29% abundance while *Merremia aegyptia,* had the lowest abundance of 2.38%. The SSI between the aboveground vegetation and the seed bank species composition shows a low similarity with the highest value of 0.1176 obtained when the vegetation was left to recover (Table 4). At plot C, one hundred and eighty-one plant species were enumerated in the seed bank comprising of 10 plant species (Table 3). Three families of plant weeds; *Asteraceae*, *Rubiaceae* and *Poaceae* with abundance values of 43%, 25% and 17%, respectively, were, however, dominant. Other seedlings recruited are the *Oxalidaceae*, 9.39%, *Portulacaceae*, 2.21% and the *Urticaceae*, 0.55%.

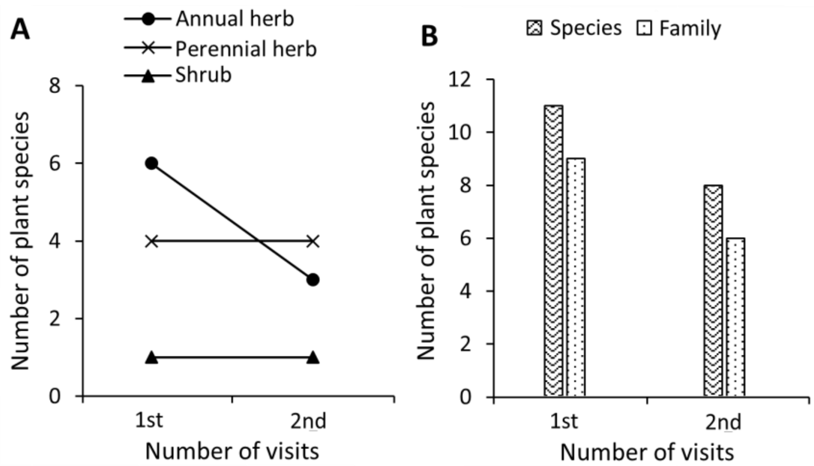

Fig. 5 Weed species at plot C experimental site. (**A**) Distribution of plant species into different habits and (**B**) distribution of plant species into different families.

Table 3 Abundance of plant species in the seed bank of the experimental plots studied in Ile-Ife.

Species name	Plot A		Plot B		Plot C	
	Individuals	RA (%)	Individuals	RA (%)	Individuals	RA (%)
Ageratum conyzoides	-	-	6	14.29	77	42.54
Amaranthus spp.	1	1.54	-	-	2	1.1
Borreria ocymoides	-	-	4	9.52	45	24.86
Chromolaena odorata	-	-	-	-	1	0.55
Cyathuila prostrata	-	-	-	-	1	0.55
Grass	5	7.69	-	-	32	17.68
Laportea aestuans	-	-	-	-	1	0.55
Melochia corchorifolia	-	-	4	9.52	-	-
Merremia aegyptia	-	-	1	2.38	-	-
Oldenlandia corymbosa	1	1.54	-	-	1	0.55
Oxalis spp.	-	-	-	-	17	9.39
Peperomia pellucida	16	24.62	-	-	-	-
Phyllanthus amarus	1	1.54	-	-	-	-
Solanum nigrum	-	-	2	4.76	-	-
Spigelia anthelmia	-	-	3	7.14	-	-
Talinum triangulare	41	63.08	22	52.38	4	2.21
Total	65	100	42	100	181	100

RA = relative abundance

Using SSI, low similarity indices were obtained for the plant community of the seed bank and the above-vegetation of the experimental plots at each period of enumeration (Table 4).

Discussion

The low or constant richness of the weed flora in the control plots compared to the experimental plots could be attributed to the fact that the vegetation cover in the control plots comprised of shrubs and regrown forest species, which offered minimum open spaces for colonization. Constant removal of weeds due to the application of herbicide on the experimental plots created open space and enhanced a new variety of colonizers on the plots. This finding contradicts Moreby and Southway [19], who demonstrated that untreated plots had greater weed density when comparing herbicide-treated and untreated plots in the headlands of winter cereal fields in southern England. Therefore, the richness of the herbicide-treated plots, in this study, could be linked to the emergence of new successional plant species from nearby plots after each episode of disturbances following herbicide treatment on the plots. Observation in this study showed that plant species that were once residents on the experimental plots were lost totally as a result of herbicide application. A notable example, reported in this study is *Stachytarpheta cayennesis*, which was once a resident of the plot B experimental site. Families contributing weed species in the flora of the experimental plots as

Table 4 Similarity indices between the experimental and seed bank at different visitations.

Seed bank	Plot location			
	A	B	C	D
A	0.0087	0.1081	0.1395	0.1333
B	0.0000	0.1176	0.0909	0.0000
C	0.1905	0.1111	ND	ND

ND = not determined

weed species in the flora of the experimental plots as shown by the study in diminishing order of importance include *Asteraceae*, *Papilionaceae*, *Amaranthaceae*, *Portulacaceae*, *Malvaceae*, *Convovulaceae* and *Piperaceae*. The plot A experimental site alone had a total of 23 families contributing to the weed flora with seven families listed as the major ones. In other words, 15 families made very minimal contributions to the weedy species across the plots. The eight plant families contributing to weedy species could be described as ideal weeds [20] since their populations grow entirely or predominantly in this anthropogenically disturbed ecosystem. Plant species recruited from the seed bank were mainly herbs with *Talinum triangulare* making the most contribution to the seed bank across the study sites. No visible tree seedlings were found in all the soil samples. The high density of herbaceous seeds in the seed bank may be related to species traits where earlier studies had reported that herbaceous seeds remain viable for a longer period in the soil than other seed types [11, 21], though the life forms of various herb species differ in the number of seeds that they deposit into the seed bank [22]. This observation is also consistent with Savadogo et al. [14] that soil seed banks were dominated by herbaceous species implying that herbaceous species have better chances of establishing from the soil seed banks following disturbance than tree species. Although species composition in the aboveground and seed bank recruitments are often related such that the seed bank allows plant species that are lost from the vegetation to be reestablished [23], a low similarity was observed between the species composition of the seed bank and above-ground vegetation in this study. Many dominant plant species in the aboveground vegetation were absent in the seed bank. Notable examples are *Bidens pilosa, Centrosema pubescens, Chromolaena odorata* and *Merremia aegyptia* at Olasode and *Hyptis suaveolens, Gomphrena celosioides* and *Bidens pilosa* at Eleweran experimental sites.

The general paucity of weedy species contributing to the seed bank can be explained by the direct effect of herbicide application on the fitness of the weed species. The weeds that will be able to contribute to the seed bank would have to tolerate or exhibit resistance to herbicide application. This is in line with the findings of Tessema et al. [24] that disturbed habitats generally have less relationship between the species present in the seed bank and the vegetation. The other scenario is that a weedy species that can escape herbicide application will be able to contribute propagules to the seed bank. Weeds that have a very short life span, for example, the so-called ephemerals will fall into this group. One example, that this study has identified, is *Oldenlandia corymbosa* and probably *Peperomia pellucida*, whose seeds appeared prominently in the seed banks across the sites. Weed plants, which have perennating organs like storage roots would also fit into this category. The example in this latter class, discovered in this study, is *Talinum triangulare*, *Paspalum conjugatum* and some unidentified grass species. It is likely that *Phyllantus amarus* achieved its fitness through early fruiting and not necessarily through a short life cycle. Despite the differences in species richness in the seed banks and aboveground vegetation, some species recurred across the plots. Examples of these are *Talinum triangulare*, *Chromolaena odorata, Amaranthus spinosus*, *Ageratum conyzoides* and some grass species.

Observations during this study did not correlate the species diversity in the study plots with the seed bank compositions. In subsequent seasons, after baseline observations, the weed flora in the study plots always had more species diversity than the seed banks. Three explanations could be offered for this disparity. The first is that the study plots are open spaces surrounded by undeveloped plots and, in some cases well-managed lawns in neighboring habitations from which propagules can be dispersed into the study plots. The second explanation is that there is a possibility that the samples for the seed bank studies were not completely representative of the plots. Another explanation is that the applications were a cocktail of herbicides including pre-emergent agents which may kill susceptible seeds in the soil.

Conclusions

Herbicide applications were very effective in reducing or limiting weed populations recruited from the seed bank and at the same time, the number of seeds added to it. Therefore, it imposes selection pressure on the weed population through a reduction of fitness. According to the findings of the study, plant species that were once residents of the

experimental plots were lost totally as a result of herbicide application since the vegetation in the urban area is exposed to varying herbicide dosages and levels of toxicity. The over-reliance on herbicides for environmental management is thus likely to raise the dosages added to the soil with great effect on seedling recruitment from the seed bank.

Conflict of interest

The authors declare no conflict of interest.

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